~~Description~~

Circuit and method for determining the offset error of a measurement that is subject to such an offset error of the coil current of an electromagnetic actuator

The invention relates to a circuit and a method for determining the offset error of a measurement that is subject to such an offset error of the coil current of an electromagnetic actuator.

BACKGROUND OF THE INVENTION

Electromagnetic actuators, which for example drive a gas exchange valve of an internal combustion engine, usually have at least one coil. An electromagnetic actuator for gas exchange valves is known for example from DE 297 12 502 U1 or EP 0 724 067 A1. It has a rest position, which lies between a closed position and an open position and from which it can be deflected by means of electromagnets.

To open or close a gas exchange valve driven by this actuator, the coil assigned to the respective final position is supplied with current, the required current being greater in the capture phase than in the holding phase, in which the gas exchange valve is held in the final position of the actuator.

If the corresponding electromagnet is in this case simply provided with current, the valve disk of the gas exchange valve hits the valve seat at high speed, which produces noise and is conducive to wear. To avoid this, the striking speed must be reduced. For this purpose, the current supply is suitably controlled.

For this purpose, it is necessary in the case of electromagnetic actuators to measure the coil current. This can take place, for example, by potential taps at a resistor connected in series with the coil. By means

Cont A4

of Ohm's law, the current can be calculated from the value of the resistance and the measured voltage drop.

The voltage drop is usually sensed with an analog circuit. In the case of such an analog circuit, an offset error is unavoidable, i.e. the measured voltage is too great or too small. A measuring device which performs an automatic offset voltage compensation is known from DE 34 29 854 A1, but a special hybrid module is required for it, which is relatively expensive. A similarly acting circuit arrangement is known from DE 34 48 182 C2. In this case, a memory module is used for the offset compensation.

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A6> The invention is based on the object of providing a circuit of an electromagnetic actuator and a method for determining the offset error of a measurement that is subject to such an offset error of the coil current of an electromagnetic actuator, with the result that no special modules are required.

This object is achieved by the invention characterized in claims 1 and 5.

A7> The invention is based on the realization that there is a final position of the actuator in which a coil is not supplied with current. If the coil current is measured at this point in time, the offset error can be determined from this.

In the case of an actuator which is used for example for driving a gas exchange valve and in the case of which, for opening or closing the gas exchange valve, the coil assigned to the corresponding final position is firstly supplied with a capture current and then with a holding current, the determination of the offset error is preferably performed on that coil which is assigned to the other final position when the coil

Cont A7

supplied with current is in the holding phase. This is because, at this point in time, it is ensured that the coil of the circuit for which the offset error is being determined is not supplied with current. In the capture phase, this is not ensured, since for example the current from its previous holding phase can still decay or, under certain circumstances, the coil is still briefly supplied with current during the capture phase for the delayed transfer of the actuator into the other final position.

Advantageous refinements of the invention are characterized in the subclaims.

An exemplary embodiment of the invention is explained in more detail below with reference to the drawings, in which:

figure 1 shows a section through an actuator for a gas exchange valve of an internal combustion engine,

figure 2 shows the time series of the current flow through the two coils of figure 1,

figure 3 shows a circuit for sensing the coil current through a coil and

figure 4 shows the states passed through during the operation of the gas exchange valve in a flow diagram.

A8 Figure 1 shows an electromagnetic actuator 1 for a gas exchange valve which is designed as a disk valve and comprises a valve disk 2 with a valve seat 3 and a valve stem 4, which is mounted in a guide 5 on the housing side and is provided at the upper end with a conical piece 6. The valve disk is moved by the

Sub B8

actuator 1 between two final positions: in an upper final position, the gas exchange valve is closed and in a lower final position it is open.

A valve spring 8 arranged between the guide 5 on the housing side and the conical piece 6 acts on the valve disk, urging it into the closed position.

The actuator 1 further comprises an upper ferromagnetic coil former 10 and a lower ferromagnetic coil former 12, which respectively carry a coil 14 and 16.

Displaceably mounted within the upper coil former 10 is an armature shaft 17, which has a plate-shaped armature 18, which lies between the two coils 14, 16. The end faces 19 and 20 of the two coil formers 10 and 12, facing the armature 18, form stops for the armature 18 and consequently define the upper and lower final positions of the gas exchange valve, in which it is open or closed.

An actuator spring 22 is clamped between the armature shaft 17 and a stop 24 on the housing side and acts on the armature 18 in the direction of the open position of the valve disk 2. The armature 18 rests on the valve stem 4. As long as the coils 14 and 16 are not supplied with current, the armature 18 is held by the valve spring 8 and the actuator spring 22 in the midway position between the two end faces 19 and 20, as represented in the drawing.

The two coils 14 and 16 are respectively supplied with current by a driver circuit 26, 27, which are activated by a control circuit 28.

For measuring the travel of the armature disk 2, a piezo element 30' is also provided on the actuator spring support. A further piezo element 32' is

provided on the guide 5 on the housing side. The output signals of the two piezo elements 30', 32' are fed to the control circuit 28, which uses them for the purpose of controlling the striking speed of the armature 6 against the coil formers 10 and 12 on the end faces 19 and 20, respectively, in such a way that the valve can be transferred into the respective final position without bouncing, with little noise, quickly and reliably.

A¶ In figure 2, the current I through the coil 14 or 16 is plotted over time t. In this case, the current I through the coil 14 is represented by a solid line, the current through the coil 16 is represented by a dashed line. This current flow is set by the control circuit 28, in order with the aid of a capture current circuit to switch the valve over into the other final position, respectively, reliably and without bouncing. For this purpose, the holding current Hs, Ho holding the armature 18 in the respective final position is switched off, so that the armature is set in motion in the direction of the other final position by the relevant, relaxing spring. At the same time, the corresponding winding 14 or 18 is supplied with the capture current Fo, Fs. For closing the valve, the coil 14 is supplied with the capture current Fs. If the armature 18 is resting on the end face 19, the coil 14 is then only supplied with lower holding current Hs, which is sufficient to hold the armature 18, and consequently the gas exchange valve, in the closed ~~position.~~

For opening the gas exchange valve, the holding current Hs through the coil 14 is switched off and the capture current Fo through the coil is switched on. Once the armature 18 has come up against the end face 20 under the action of the valve spring 8 and the actuator spring 22 and also the magnetic field generated by the

capture current Fo, the supply of current to the coil 16 is switched over to the holding current Ho and the valve disk 2 is held in the open position. To close the valve again, the holding current Ho is analogously switched off and the capture current Fs is switched on.

A10> In other words, the gas exchange valve passes through the states I to IV represented in figure 4. In state I, the valve is closed and the holding current Hs is flowing in the coil 14. Next, in state II, the valve is opened, for which purpose the coil 16 is supplied with the capture current Fo, and the holding current Hs in the coil 14 slowly decays. Once the armature 18 has come up against the end face 20, the supply of current to the coil 16 is switched over to the holding current Ho and the valve is open (state III of figure 4). For closing, the coil 14 is in turn provided with capture current, which is represented in figure 4 as state IV. Once the armature 18 has come up against the end face 19, state I exists again.

In order then to be able to use the current through the coil 14, 16 in the control circuit 28, a measurement of the coil current is necessary. The driver circuit required for this purpose is represented together with a more accurate representation of the control circuit 28 by way of example in figure 3. Figure 3 shows the driver circuit 26 for the coil 14. The driver circuit 27 is designed in an analogous way.

As can be seen in figure 3, the coil 14 is activated by an asymmetric half-bridge. In this case, the coil 14 is connected between a highside FET Th, which on the other hand is connected to the supply voltage Vcc, and a lowside FET Tl, which in turn is connected on the other hand via a resistor R to the reference potential. Connected in the forward direction between the reference potential and the connecting nodes of the

Cont A10

coil 14 to the highside FET Th is a diode D2. Connected in the forward direction between the connecting nodes of the coil 14 to the lowside FET Tl and the supply voltage Vcc is a diode D1. Finally, the supply voltage Vcc is connected to the reference potential via a capacitor C. Between the lowside FET Tl and the reference potential there lies a resistor R.

A desired current in the coil 14 is controlled by switching the highside and/or lowside FET Th, Tl on and off. In this case, the actual current is measured by the voltage drop across the resistor R in the lowside branch. The voltage drop is tapped by a differential amplifier 30, the output value of which is fed via an adding node 31 to a filter 33 and on to an analog/digital converter 34 and a microcontroller 35. In the determination of the voltage drop by means of the differential amplifier 30, an offset error is unavoidable, whereby the actual current is falsified.

A11> If the desired current is zero, the highside and lowside FETs Th, Tl are turned off. In this state, no current flows through the resistor R and the voltage at the input of the differential amplifier 30 is zero. On account of the internal construction of the differential amplifier 30, it is possible however for a negative voltage to be present at the output as the result of an offset error. In the case of a measuring chain of a unipolar construction, as usually used in automotive electrical engineering, however, a negative measuring voltage is undesired. For this reason, an artificially generated offset is added on at the adding node 31. For this purpose, the output of a constant-voltage source 32 is additionally fed to the adding node 31. Consequently, there is always a positive voltage present at the input of the filter 33.

Cont A11

For determining the offset error, it must be ensured that the resistor R is not flowed through by a current. This can only be ensured for the coil 14 in the holding phase of the other coil 16, since this concerns a final position in which the coil 14 for the circuit 26 of which the offset error is to be determined is not supplied with current. After determination of the offset error I_o of the non-activated coil, the actual current I_m can be corrected as follows when the coil is next activated in the then-following cycle:

$I_{corr} = I_m - I_o$

Preferably, the offset error I_o is measured by being sampled several times in the coil 14 and a weighted average value is formed as follows by using the measured values:

$I_{o,i} = I_{o,i+1} \cdot (1-k) + I_m \cdot k$

A12 This weighted average value is one possible form of low-pass filter; others are conceivable. In this case, $I_{o,i}$ is the ith measurement of the offset error, I_m is the actual value of the current (raw value of the analog/digital converter 34) and k is a weighting factor.

This low-pass filtering takes account of the realization that the offset error I_o fluctuates in a temperature-dependent manner and changes only slowly with respect to the sampling rate with which the offset error is determined.

The invention was described above in the case of application to an actuator 1 for a gas exchange valve of an internal combustion engine. However, it is not restricted to this, but may also be applied to other actuators. The actuator also does not have to have two coils; it is sufficient for there to be one final position in which a coil is not supplied with current.